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Insights from Quantitative Risk Monitoring Model Development for LPSD Period

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1. Introduction

To address regulatory issues for an APR1400 type NPP (Nuclear Power Plant) for an overseas country, a quantitative RMM (Risk Monitoring Model) for LPSD (Low Power and Shut Down) period was developed. Though several quantitative RMMs such as RIMS for NPPs in Korea have already been developed, all of them are for at-power period. During the development of the LPSD quantitative RMM, some technical issues were encountered which have not been considered during quantitative RMMs development for at-power in Korea.

In this paper, a general process for an LPSD quantitative RMM is listed, and insights gained in relation to technical issues and solutions for during LPSD quantitative RMM development were described in more detail. It is believed that the insights described in the paper can provide PSA (Probabilistic Safety Assessment) practitioners with very useful information for future quantitative RMM development during LPSD operation period in Korea.

2. Process for LPSD quantitative RMM development

The overall process for the LPSD quantitative RMM development was as follows.

- Step 1: PSA modifications for single database and single recovery rule file
- Step 2: Initiating event frequency adjustment
- Step 3: Systems alignment model development
- Step 4: Support systems initiating event FT (fault tree) development
- Step 5: LPSD operation characteristics implementation
- Step 6: Symmetricity implementation
- Step 7: Single top FT development for CDF (Core Damage Frequency) and LRF (Large Release Frequency) for each POS (Plant Operation Status)
- Step 8: LPSD quantitative RMM database development

LRF as well as CDF is considered as the one of the risk metrics for risk-informed applications in the subject country. The LRF was defined using the results in NUREG/CR-6094[1].

Steps 1, 3, 4, 7, and 8 are almost the same as those of quantitative RMM development for at-power. Steps 2, 5, and 6 are considerably different from those of quantitative RMM development for at-power. Therefore, the insights described in this paper are related to the steps 2, 5, and 6. In addition, some insights gained from LPSD quantitative RMM applications were also described.

3. Insights gained from LPSD quantitative RMM development

3.1 Initiating event frequency adjustment

The quantitative RMM should provide CDF and LRF for a specific plant configuration with per POS year basis. The plant configurations considered in quantitative RMM are mainly system alignment and equipment OOS (Out of Service) due to test or maintenance. In base LPSD PSA, initiating event frequency is calculated per calendar year basis. Therefore the initiating event frequency should be modified to per specific POS year basis rather than calendar year basis in quantitative RMM.

In base LPSD PSA, most of the initiating events are modeled with two basic events as follows.

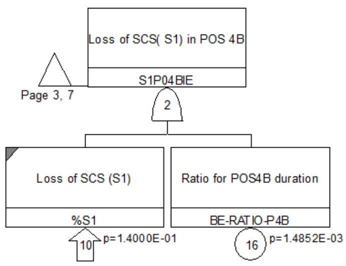

Figure 3.1-1 Initiating Event Modeling in Base LPSD PSA

%S1 is an initiating event with frequency per one POS year duration basis and the other basic event (BE-RATION-P4B) is time fraction basic event of the relevant POS for the initiating event. By setting the time fraction basic event to 1.0, the initiating event frequency can be changed to per specific POS year basis.

However, there are also some demand base initiating events in LPSD PSA which are mainly caused by some specific operation and/or test. Typical examples for these initiating events are RCS (Reactor Coolant System) over-draining events during POS 5 and POS 11, and POSRV (Pilot Operated Safety Relief Valve) stuck open event during POS 2. These initiating events can occur during a specific operation or a specific test interval. The operation/test duration is generally very short but not during the entire POS year. To reflect this characteristic into LPSD quantitative RMM, three options below can be used.

- Option 1: Using average POS duration as the operation/test duration for the relevant demand base initiating events
- Option 2: Using administrative task duration as operation/test duration for the relevant demand base initiating events
- Option 3: Separate treatment of these initiating events by calculating CDP (Core Damage Probability) and LRP (Large Early Probability) using initiating event probability instead of initiating event frequency

In the aspect of realism, option 3 should be used because the specific operation/test duration relevant to the initiating events are very short. However, option 1 or 2 can be used in the aspect of providing risk information for operation staff in NPPs. For actual risk-informed application, option 3 should be used.

If the option 1 is used, the initiating event frequency adjustment for quantitative RMM can be done using the equation below.

IEF for RMM = IEF in Base PSA * O/H duration / POS duration

By applying the equation above, new initiating event frequencies applicable for LPSD quantitative RMM can be calculated. The examples of modified initiating event frequencies are shown in the figure below.

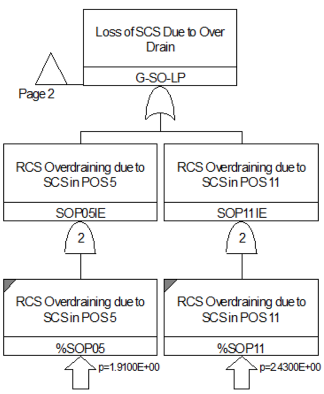

Figure 3.1-2 Modified Initiating Event Modeling for SO Initiating Event

If the option 2 is used, the initiating event frequency adjustment for a quantitative RMM can be done with the equation above by using administrative task duration instead of POS duration. For the subject NPP, option 1 is selected for pilot application.

As can be seen in the figure above, the adjusted frequencies for demand base initiating events are often greater than 1.0. Therefore FTREX[2] option of AMCS should be appropriately used for consistent MCSs (Minimal Cut Sets) generation.

3.2 LPSD operation characteristics implementation

The NPP would have different configurations during each POS for different O/Hs. In base PSA, the differences of the plant configuration for each O/H are modeled in configuration control files which reflect the operational characteristics of each POS. However, in base PSA, the modeled plant configuration is average-based. This means that there might be high possibility of plant configuration change for each plant refueling overhaul. To implement this variation of plant configuration for each POS, flag events modeled in base PRA should be classified into two categories. One is the group which is directly subject to a specific POS. The other is the group which is not directly subject to a specific POS. " Not directly subject to a specific POS" means that it can be changeable for each plant refueling overhaul.

The flag events being directly subject to a specific POS should be remained as they are in base PSA model for LPSD quantitative RMM development. Rather, the flag events not being directly subject to a specific POS condition should be changed and should be incorporated into the LPSD quantitative RMM. Thus, quantitative RMM user can control the plant configuration with these flag events reflecting actual plant configuration.

Most of the flag events not directly being subject to a specific POS condition are related to the components OOS. For example, emergency Diesel generator Alpha is OOS for maintenance during POS 3B ~ POS 7 in base PRA model. However, the schedule for the emergency Diesel generator Alpha maintenance could be changed for each plant refueling overhaul.

3.3 Symmetricity implementation

Asymmetry in PRA model is mainly due to the assumption of failure location for initiating event and/or asymmetric alignment for shared/swing components or systems. For the LPSD PSA of the subject NPP, there are no initiating events which can cause asymmetry. However, the alignment of AAC DG (Alternate Alternative Current Diesel Generator) can cause big asymmetry because it plays an important role for mitigating SBO (Station Black Out). To resolve the asymmetry with regard to AAC DG alignment, the principles below were implemented into the LPSD quantitative RMM.

- AAC DG is aligned to a train with the EDG (Emergency Diesel Generator) being OOS.
- If both EDGs are OOS or in service, AAC DG is aligned to a train with an SC(Shutdown Cooling) pump is running

To implement the principles above, 4.16kV train Alpha has the flag combination logic below.

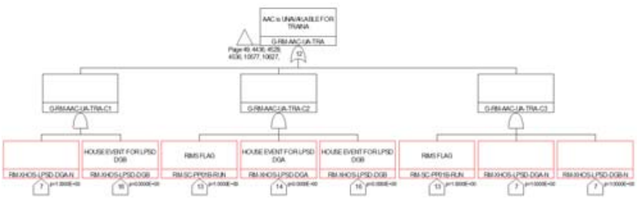

Figure 3.3-1 AAC DG alignment logic for Train Alpha

To implement the principles above, 4.16kV train Bravo has the flag combination logic below.

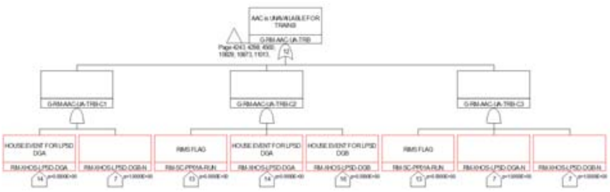

Figure 3.3-2 AAC DG alignment logic for Train Bravo

Another option to be used is pre-determined AAC DG alignment using system alignment function even though actual AAC DG alignment is dependent on situations during the accident requiring its operation.

3.4 LPSD risk monitoring application

Difficulties for LPSD quantitative RMM applications are related to the setting of risk color. For at-power quantitative RMM, average CDF and LRF are just a little higher than no maintenance CDF and LRF. On the other hand, for LPSD quantitative RMM, average CDF and LRF are much higher than no maintenance CDF and LRF. In addition, the instantaneous CDF and LRF are much higher than base PSA because the instantaneous CDF and LRF are calculated per POS year basis rather than calendar year basis. Therefore, risk color should be determined considering the delta CDF and LRF between no maintenance and average maintenance for each POS independently.

5. Conclusions

In this paper, a general process for an LPSD quantitative RMM was listed, and insights gained in relation to technical issues and solutions for during LPSD quantitative RMM development were described in more detail. It is believed that the insights described in the paper can provide PSA practitioners with very useful information for future LPSD quantitative RMM development.

REFERENCES

[1] Hanson, A. L., R. E. Davis, and V. Mubayi, "Calculations in Support of a Potential Definition of Large Release, "NUREG/CR-6094", BNL-NUREG-52387, Brookhaven National Laboratory, May 1994.
[2] EPRI, FTREX 1.9 Software Manual, Product ID #30022012968, 2018.